Program Overview: Fundamental Symmetries

Wick Haxton

Nuclear Science Division
Lawrence Berkeley National Laboratory

ARE THE FUNDAMENTAL INTERACTIONS THAT ARE BASIC TO THE STRUCTURE OF MATTER FULLY UNDERSTOOD? - 2015 NP LRP

Outline

Fundamental Symmetries and Neutrinos

- Who we are
- Our goals
- Recent highlights
- Near-term plans
- Long-term plans
- Theory connections

Presentation

- CUORE: Yury Kolomensky, Brian Fujikawa
- Majorana: Alan Poon
- SNO+: Gabriel Orebi Gann

Who we are

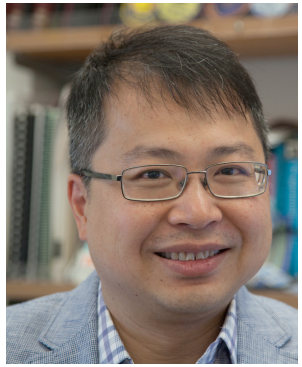
Brian Fujikawa
CUORE
NSD Staff Scientist

Wick Haxton
Theory
UCB Faculty
NSD Senior Fac. Sci

Yury Kolomensky
CUORE
UCB Faculty
NSD Senior Fac. Sci.

Gabriel Orebi Gann
SNO+
UCB Faculty
NSD Faculty Scientist

Yuan Mei
CUORE, instrumentation
NSD Staff Scientist



Alan Poon
Majorana, KATRIN
NSD Staff Scientist

We are also students, postdocs, visitors

CUORE

- Two LBL-based postdocs: Benjamin Schmidt
  Bradford Welliver
- Four campus-based postdocs receiving lab training
- Five campus undergraduates receiving lab training

Majorana

- Two LBL-based postdocs: Jordan Myslik
  additional hiring in process
- One campus-based graduate student receiving lab training
- Two campus-based undergrads receiving lab training

SNO+

- Three campus-based and one PD-based postdocs
- Three campus-based graduate students receiving lab training
- Two campus-based undergrads receiving lab training

Our activities

Major player in current generation ββ decay experiments
CUORE (US lead), Majorana, SNO+

Participant in the tritium end-point experiment KATRIN

Operate low-level counting facilities at LBL and Sanford Lab

Leading final-stage analysis of the SNO solar neutrino experiment

Continued involvement in our "legacy" experiment KamLAND

Involved in feasibility studies of next-generation neutrino detectors
(e.g., see LDRD discussion of THEIA)

Our goals

Determine whether lepton number is violated, and thus whether neutrinos might be their own antiparticles

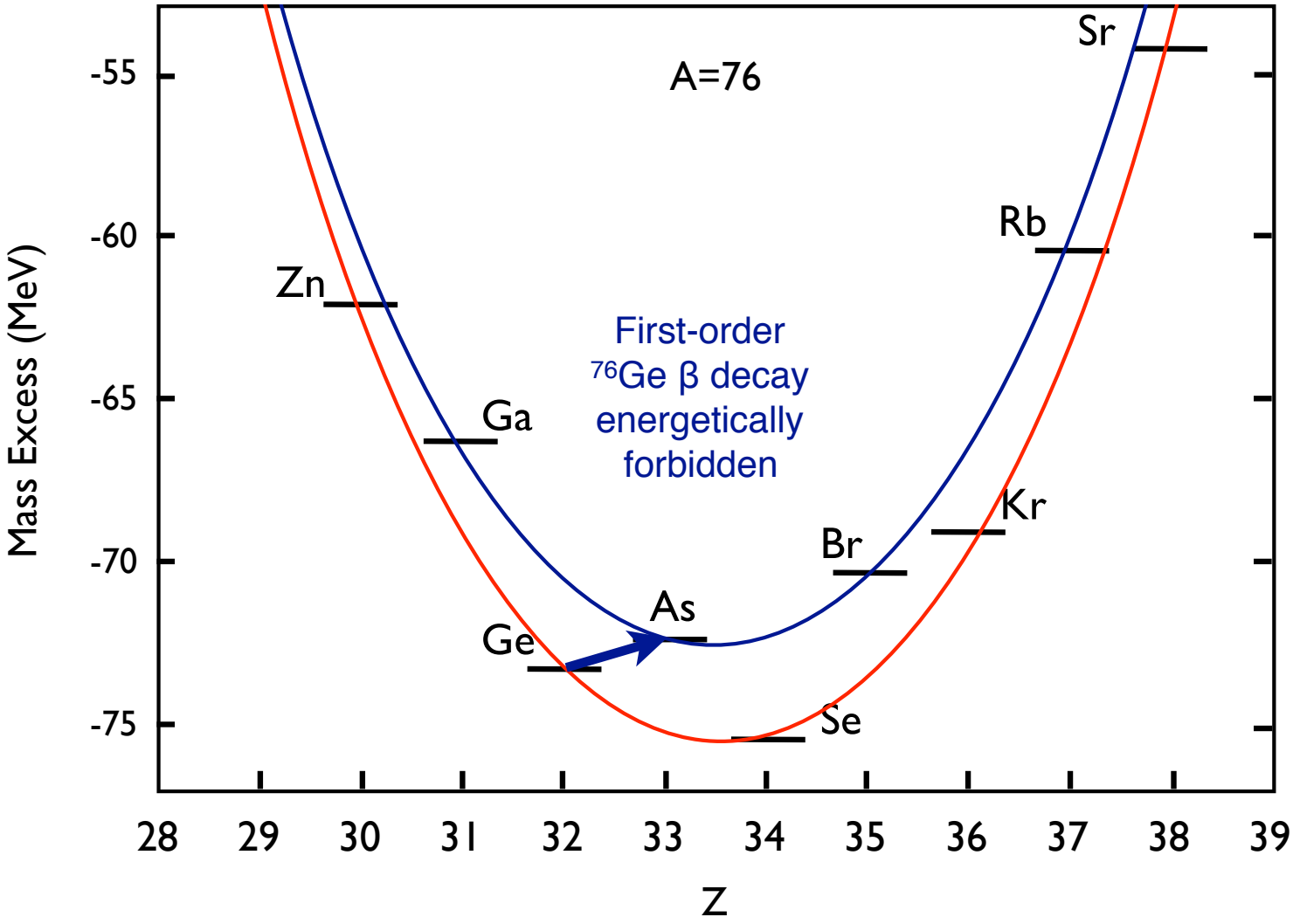
$lepton$	l_e
e^-	$+1$
e^+	-1
ν_e	$+1$
$\bar{\nu}_e$	-1

Double Beta Decay

$$(N, Z) \rightarrow (N-2, Z+2) + 2e^- + 2\bar{\nu}_e$$ lepton number conserving

$$(N, Z) \rightarrow (N-2, Z+2) + 2e^-$$ lepton number violating

Our goals


A=76
Mass Excess (MeV)
-55
-60
-65
-70
-75
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Ga
Ge
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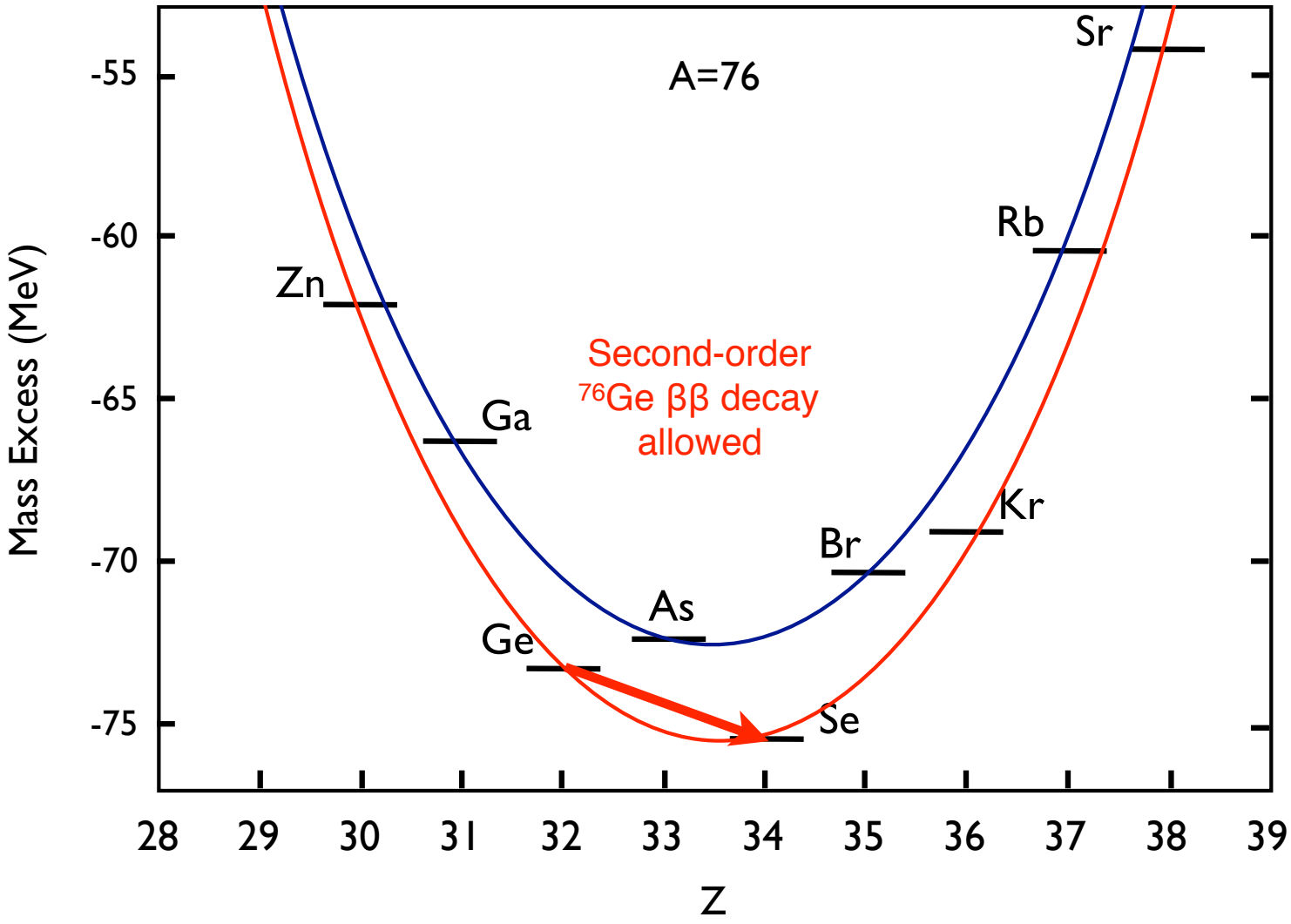
Br
Kr
Rb
Sr
First-order
^{76}Ge β decay
energetically
forbidden

Our goals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Second-order
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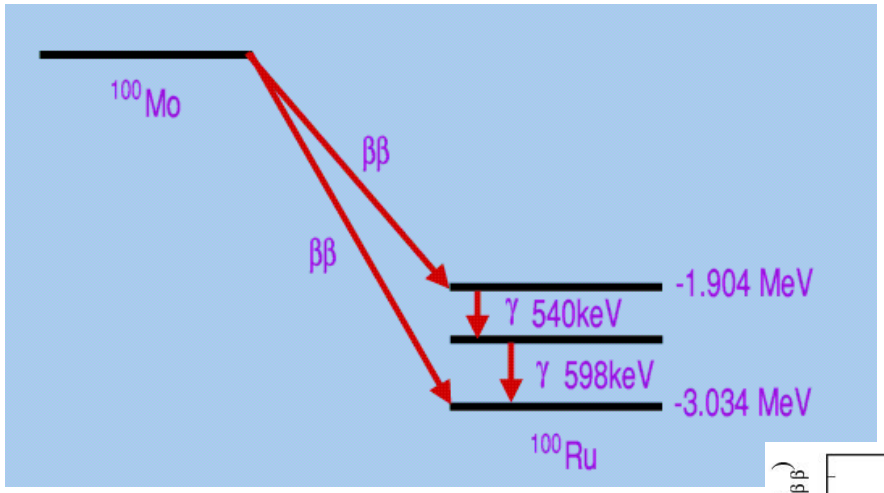
allowed

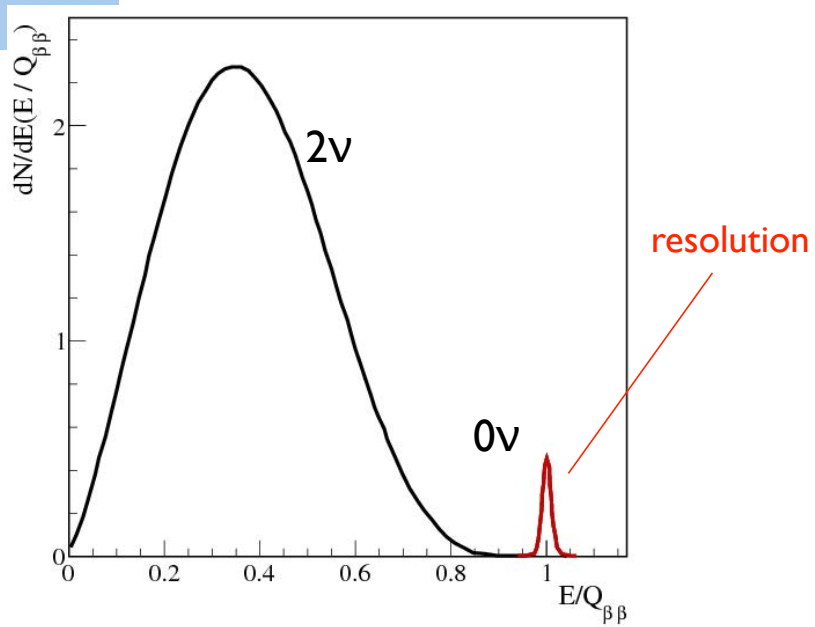
Our goals



The two ββ decay modes can be distinguished in experiments

spectrum of summed energy for the two outgoing electrons:

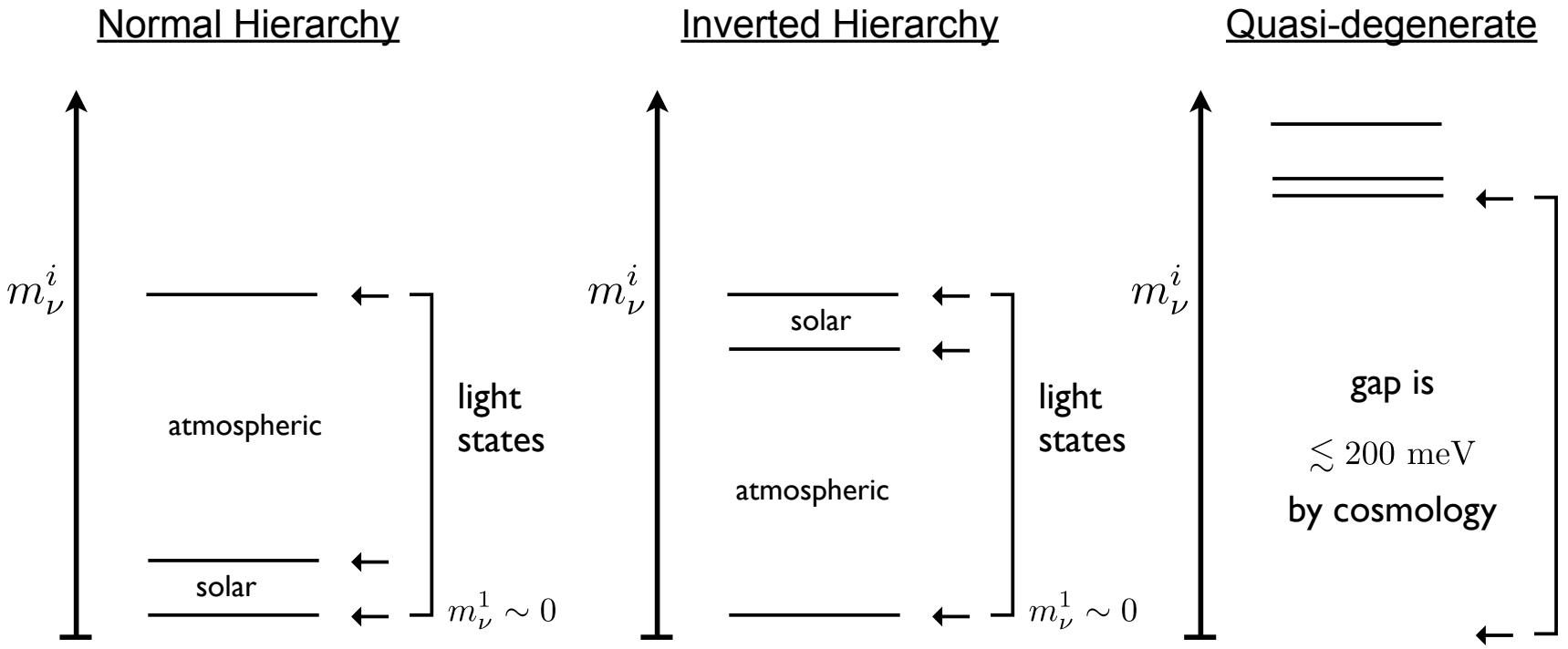
with good detector energy resolution, the 0v and 2v modes can be separated



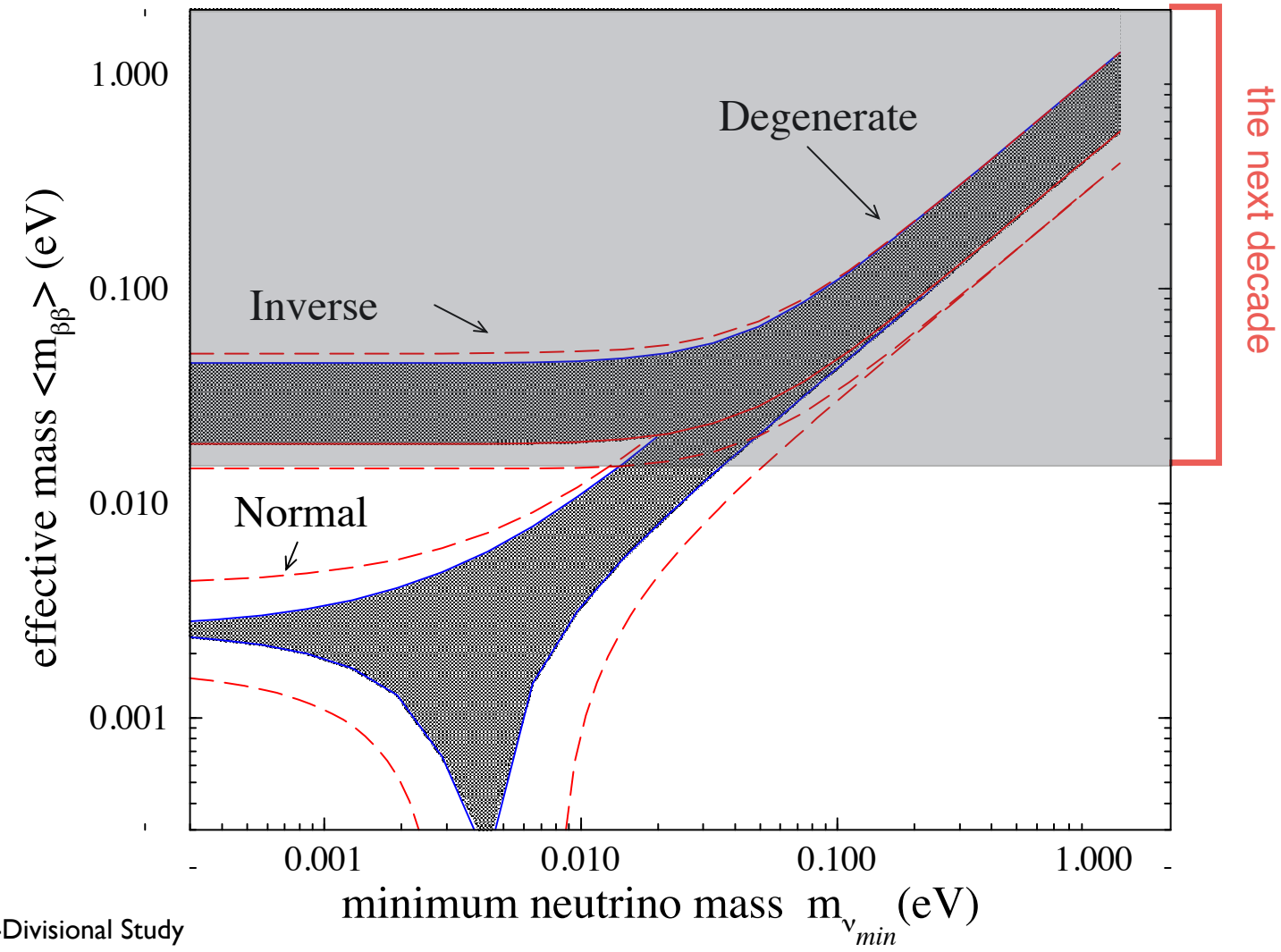
Our goals

Light Majorana neutrino "standard" case: three scenarios allowed by oscillation results

$$\langle m_{\beta\beta} \rangle_{\text{light}} = \sum_{i=1}^{n} U_{\text{ei}}^{L} U_{\text{ei}}^{L} \ \lambda_i \ m_\nu^i$$



Our goals

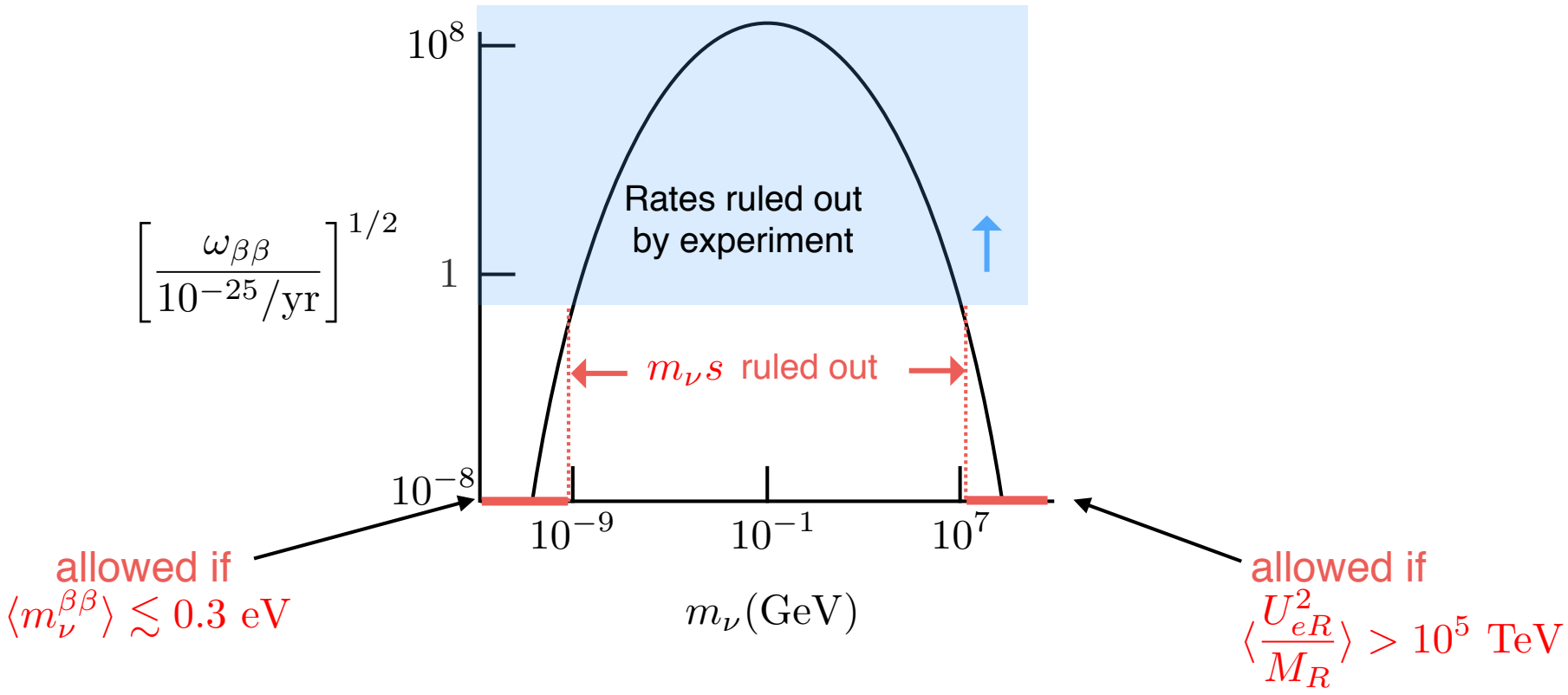


APS Multi-Divisional Study

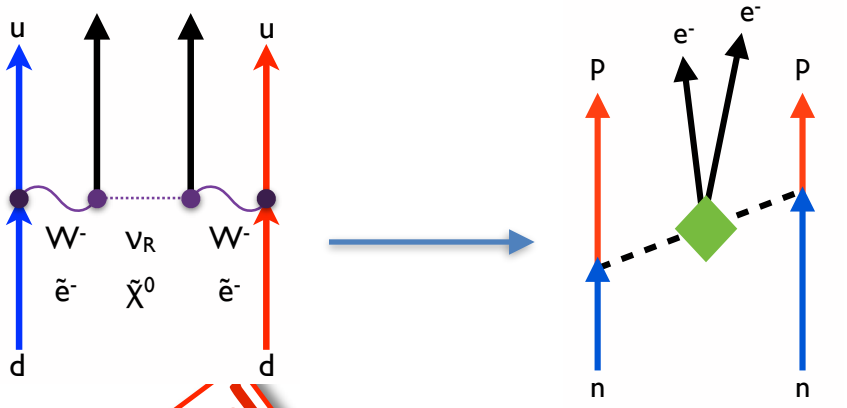
Our goals

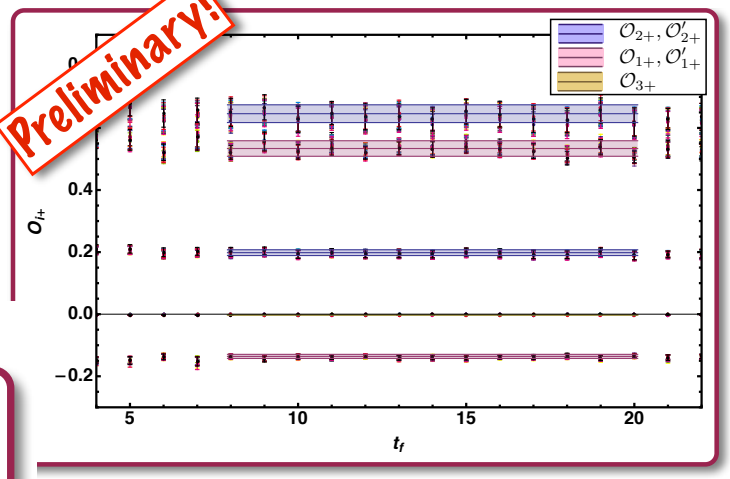
Theory - experiment connections at LBL:

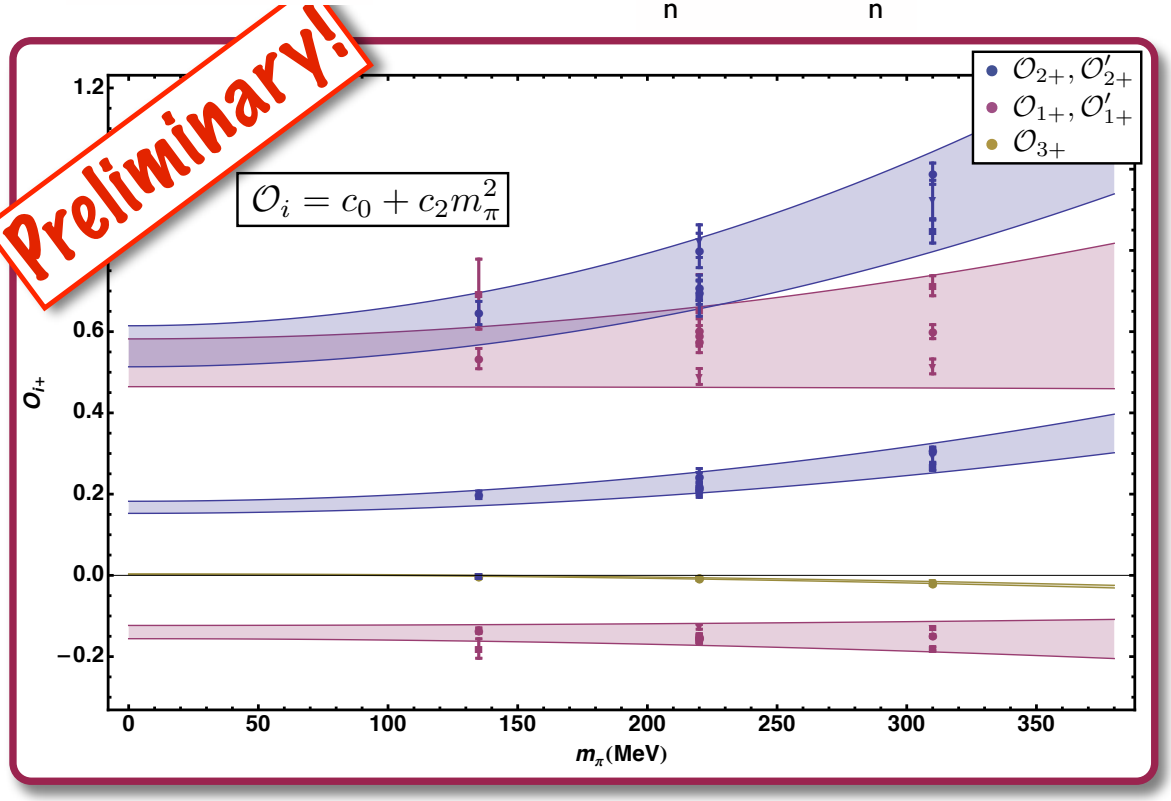
Experiments also limit very heavy Majorana neutrinos - short-range operators uncertain, but can be determined well by LQCD



Our goals

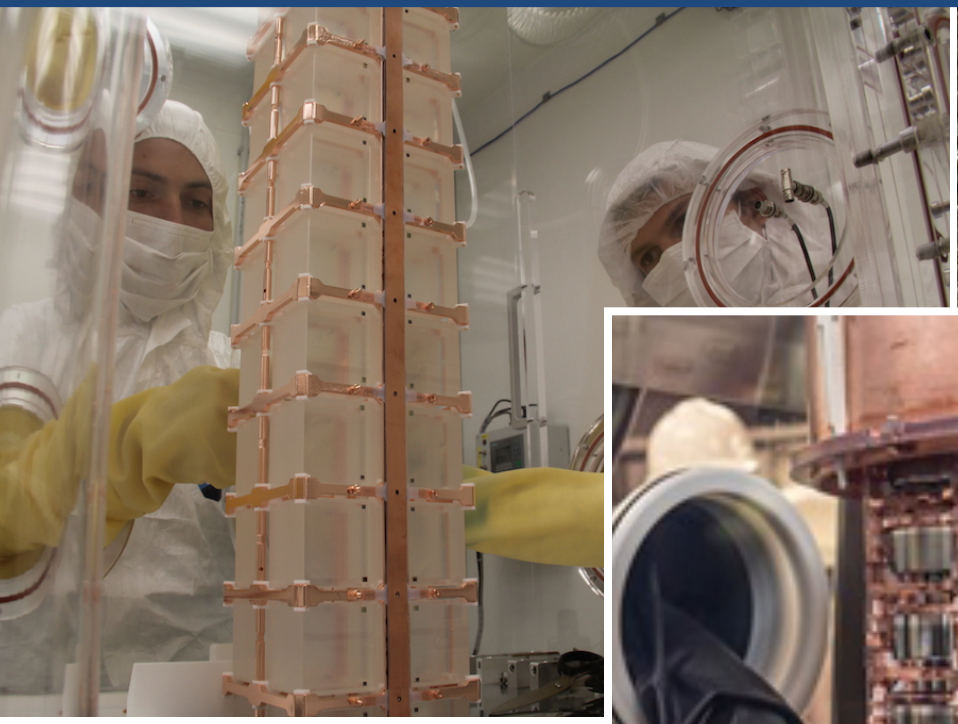






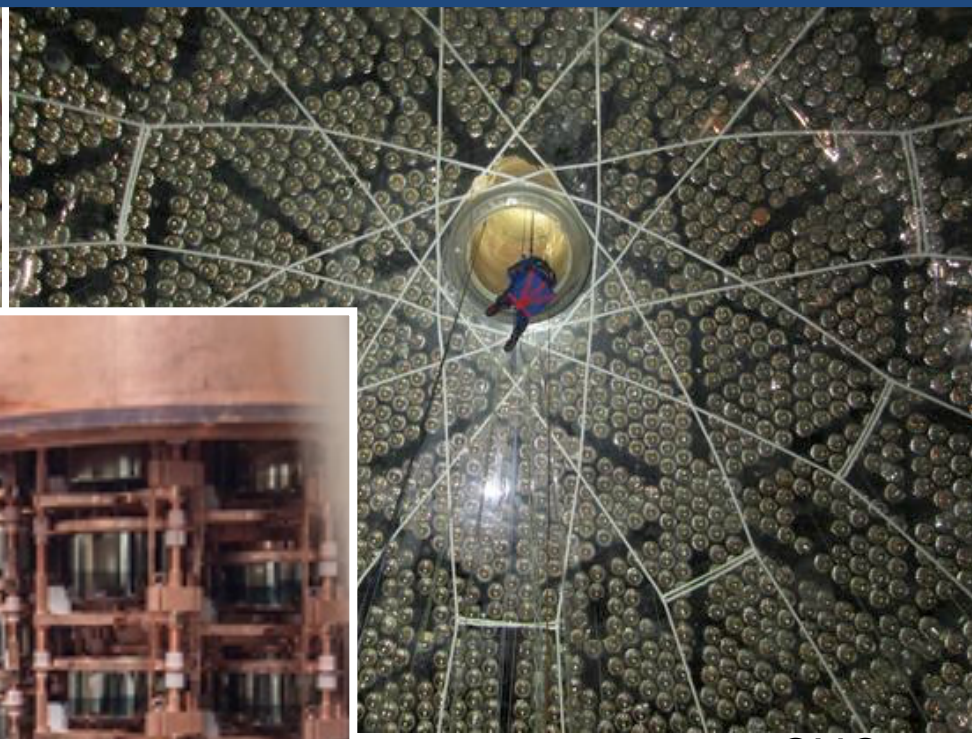
The LO EFT result is a pionic calculation, yielding a long-range operator

Recent highlights



CUORE

Majorana Demonstrator



SNO+

DOUBLE BETA DECAY DEMONSTRATOR EFFORTS AT LBL

RECOMMENDATION II: 1-TON-SCALE US-LED NEUTRINOLESS ββ DECAY EXPERIMENT - 2015 LRP

Recent highlights

CUORE and CUORE-0

- Full CUORE-0 run finished 3/15, final data analysis nearly complete
- CUORE class-1000 cleanroom, surrounding cryostat, installed
- Final assembly and commissioning of CUORE begins: all 19 towers now installed
- Delivered, installed, and configured the CUORE compute cluster for data analysis at LNGS, and the run control and monitoring clusters at LNGS and LBL
- Developed automated analysis tools for CUORE, capable of handling the 20-fold increase in data
- Continued R&D for “next-generation” bolometer technology based on CUORE
- Continued leadership roles: BF leads Computing Infrastructure working group and chairs Speaker Bureau; Kolomensky is US spokesperson and Executive Board member

Recent highlights

Majorana Demonstrator

- Signal readout electronics for MJD delivered and commissioned, and are operating. The measured full-width-at-half-maximum of 150-180 eV will allow an expanded low-energy program.
- Completion of MJD detector string assembly. LBNL managed the string assembly process at Sanford Lab.
- Module 1 cryostat data analysis and initial results. LBL led the development of data reduction cuts for Module 1 data.
- Low-background R&D for Majorana. Papers were published on low-background electronic circuitry fabrication and on the community-standard radio-assay database

Recent highlights

SNO+

- A long campaign to identify and stop a detector leak was completed successfully, allowing water filling to proceed.
- LBL took on coordination and a substantial portion of the development for the SNO+ DAQ software.
- LBL continued to coordinate analysis groups, focused in 2016 on imminent water data
- LBL motivated and designed a very successful second-round test of SNO+ data processing and analysis systems.
- PI OG was part of the internal review for a white paper summarizing the SNO+ physics program, now published

Recent highlights

Other efforts

- SNO: LBNL led analyses focused on the hep solar neutrino flux, neutrino lifetime limits, and atmospheric neutrinos
- KATRIN: Two papers were published on the sensitivity to sterile neutrinos; studies continued on the impact of the dominant background, Rydberg atoms within the main spectrometer. LBNL continued to provide support in radioassay.
- Low-background counting facility: AP has continue management of the Berkeley LBF at LBNL and SURF. A second detector for underground counting at SURF was refurbished and commissioned. LBNL assisted in other detector installations.

Near-term plans

CUORE

- Next major milestones is the start of cool-down in Nov. 2016 and commissioning of the full detector by February FY17, with first results expected by the end of 2017
- LBL will play a major roll in commissioning and operations, having major responsibilities for run control and monitoring, computing infrastructure, and temperature stabilization
- LBL will play a major role in the analysis of first data
- LBL will continue R&D for next-generation successors to CUORE

Near-term plans

Majorana Demonstrator

- The LBL group activities will transition from construction and commissioning, to analysis.
- R&D efforts will focus on detector advances in support on a ton-level Ge experiment, including development of improved readout systems and the optimization of electronics circuitry for low-background environments.
- LBL will investigate the use of HPC systems at NERSC (e.g., CORI) for MJD simulations and analysis, and for its next-generation successor

Near-term plans

SNO+

- LBL will continue to lead analysis coordination for both solar neutrinos and double beta decay, and will play active roles in detector management and PMT calibration
- LBL will play a lead role in detector commissioning, to begin in two weeks
- LBL expects to lead efforts on an early SNO+ paper from the initial water detector phase

Near-term plans

Other efforts

- The LBL KATRIN group will organize and implement a “data challenge” in preparation for tritium data taking.
- The KATRIN group will investigate the use of HPC NERSC compute systems for KATRIN field calculations and simulations.
- LBL will continue to provide radioassay support for a range of community underground science efforts.
- The LBL SNO group will complete its analysis of legacy data sets, leading to 4-6 final SNO publications.
- R&D and community coordination will continue on a large-volume water-based liquid scintillator detector

Long-term plan/aspirations

<u>LBL wants to play a major role in the next-generation double beta decay program aimed at the inverted hierarchy.</u>

Thus would entail defined and specific tasks for which the NSD would take responsibility, leading the science and engineering.

We view our present program in the context of national efforts to explore technologies - defining the most promising path forward.

We see LBL opportunities in a US-based and US-led experiment; we also see opportunities for significant partnerships overseas, depending on technological developments.

We see opportunities for partnering with campus to strengthen our local group in preparation for a G2 ββ-decay effort.

Prizes and honors (since 2013)

Senior Honors

2016 Breakthrough prize in Fundamental Physics: SNO

LBL recipients: Yuen-dat Chan, Gabriel Orebi-Gann, Alan Poon, Alan Smith

2016 Breakthrough prize in Fundamental Physics: KamLAND

LBL recipients: Yuen-dat Chan, Brian Fujikawa, Alan Poon

2014 APS Fellowship: Alan Poon

2013 Community Partnership Award, Boy Scouts of America:

NSD Nuclear Science Day Team, Alan Poon et al.

2014 Hellman Faculty Award: Gabriel Orebi Gann

2013 DOE Early Career Award: Gabriel Orebi Gann

Prizes and honors (since 2013)

Student/Postdoc Honors

2016 Helmholtz Doctoral Award: Benjamin Schmidt

2017 Dissertation Prize in Nuclear Physics: Jonathan Ouellet

2013-15 Humboldt Foundation Lynen Fellow: Susanne Mertens

Leadership roles (2013-)

Program, national, international leadership roles of group members

- US Spokesperson, CUORE Experiment: Yury Kolomensky
- Leader, International THEIA Interest Group: Gabriel Orebi Gann

Leadership roles (2013-)

Committee chair service

- CUORE Computer Infrastructure Working Group: Brian Fujikawa
- MJD Publications Committee: Alan Poon
- Selection Committee, APS Prize to a Faculty Member for Research in an Undergraduate Institution: Alan Poon
- KATRIN Publications Committee: Alan Poon
- Majorana Mentoring Committee: Alan Poon
- NSD Organizing Committee, Nuclear Science Day: Alan Poon
- Physics Analysis, Sudbury Neutrino Observatory: Gabriel Orebi Gann
- Physics Analysis, SNO+: Gabriel Orebi Gann

Leadership roles (2013-)

Committee member service

- CUORE Executive Board: Yury Kolomensky
- CUORE Collaboration Council: Yury Kolomensky, Brian Fujikawa
- CUORE Speaker Board: Brian Fujikawa
- CUORE Vetting Board: Brian Fujikawa
- NSD Safety Council: Brian Fujikawa
- LBNL Safety Advisory Committee: Brian Fujikawa
- APS DNP Program Committee: Alan Poon
- APS DNP Education Committee: Alan Poon
- APS Working Group on US Next Generation Science Standards: Alan Poon
- NSF Robert Noyce Teacher Scholarship Selection Committee: Alan Poon
- Majorana Executive Committee: Alan Poon
- KATRIN Collaboration Board: Alan Poon
- Director review committees (conceptual, preliminary design, final design, CD2/3b, CD3c) LUX-ZEPLIN (LZ): Alan Poon

Leadership roles (2013-)

Committee member service (cont.)

- SURF Radioactivity Contamination Committee: Alan Poon
- Ad Hoc Steering Committee, Neutrinos and Fundamental Symmetries: Alan Poon
- THEIA Proto-collaboration Coordination Group: Gabriel Orebi Gann
- MiniCLEAN Scientific Board (Executive Committee): Gabriel Orebi Gann
- SNO+ Scientific Board (Executive Committee): Gabriel Orebi Gann
- SNO Scientific Board (Executive Committee): Gabriel Orebi Gann
- SNOLab Strategic Planning Committee: Gabriel Orebi Gann

Conference organization (2013-)

- Organizing committee, Stuart Freedman Symposium (2014):
  Chair: Brian Fujikawa Member: Yury Kolomensky
- Organizing committee, DBD14 and DBD16: Brian Fujikawa
- Convenor, CPAD-2015 workshop "New Technologies for Discovery":
  Yury Kolomensky
- Co-convenor, Workshop on Intermediate Neutrino Program: Yury Kolomensky
- International Scientific Advisory Committee, Low Radioactivity Techniques Workshop, 2015 and 2017: Alan Poon
- Scientific secretary, International Workshop on Double Beta Decay and Neutrinos: Alan Poon
- Organizing committee, FS&N Town Meeting and Pre-Town Meeting for the LRP in Nuclear Physics: Alan Poon
- Local organizing committee, Conference for Undergraduate Women in Physics 2014 (Berkeley): Alan Poon
- Organizing committee, Mini-symposia on Beyond the Standard Model Physics and the Reactor Neutrino Anomaly, DNP2016: Alan Poon
- Chair, Organizing Committee, Frontiers in liquid Scintillator Technology, 2016: Gabriel Orebi Gann

Conference organization (2013-)

- Member, organizing committee, Conference on the Intersections of Particle and Nuclear Physics, 2015: Gabriel Orebi Gann
- Convenor, Baryon and Lepton Number Violation Conference, 2015: Gabriel Orebi Gann
- Convenor, Workshop in Intermediate Neutrino Program Detector R&D Working Group: Gabriel Orebi Gann
- Member, National Organizing Committee, Conference for Undergraduate Women in Physics series: Gabriel Orebi Gann
- Member, organizing committee, Fundamental Symmetries community planning Town Hall: Gabriel Orebi Gann
- Member, organizing committee, Workshop on Next-Generation Solar Neutrino Detection at Jinping: Gabriel Orebi Gann
- Chair, organizing committee, Large-Scale WbLS Detector in the LBNE Beam: Gabriel Orebi Gann
- Chair, local organizing committee, West Coast Conference for Undergraduate Women in Physics: Gabriel Orebi Gann
- Member, organizing committee, Stuart Freedman Symposium: Gabriel Orebi Gann
- Member, organizing committee, TAUP13 Summer School: Gabriel Orebi Gann
- Member, organizing committee, TAUP13: Gabriel Orebi Gann

Publication and talk counts (2014-)

CUORE, Majorana Demonstrator and KATRIN, SNO+

(Data includes only 2014-16)

- total publications: 59
- letter publications: 3
- invited talks: 73

Two additional publications and 12 invited talks associated with Topmetal effort (see Yuan Mei's talk)

Synergies

LBL/Berkeley Theory Program

- Topical Collaboration on Double Beta Decay and Fundamental Symmetries
  NSD members: Haxton, Walker-Loud
  Focus: Double beta decay mechanisms, nucleon/nuclear matrix elements, and effective operators

- N3AS: NSF's Network for Neutrinos, Nuclear Astrophysics, and Symmetries
  NSD members: Haxton (PI), Kasen
  Focus: Postdoctoral training in the general areas of neutrinos, nuclear astrophysics

- SciDAC III CalLat Collaboration: Multiscale Nuclear Physics
  NSD members: Haxton (PI), Walker-Loud, Nicholson, McElvain
  Focus: various, but includes both lattice QCD calculations of short-range operators for double beta decay, and state-of-the-art numerical methods for very-large-basis shell model calculations

Synergies

GRETA/GRETINA

- Development of state-of-the-art Ge detector technology and analysis techniques for future experiments in nuclear physics

NSD Applied Nuclear Physics

- Development of low-noise, low-background readout electronics for future neutrinoless double-beta decay experiments and applied applications (such as reactor monitoring). Postdoctoral and student training in semiconductor detector technology.

Topmetal

- Significant interest in use of Topmetal in high-pressure gaseous Xe experiments that may be able to image the two-electron final state (NEXT in Canfrac, analogous effort at Jinxing) - see Yuan Mei's talk

Synergies

Underground Facilities

- SNOLAB: provide availability and maintenance of standard radio-assay database of the underground physics community
- SURF: provide low-background counting services for the underground physics community
- LNGS/MPIK: development of the most sensitive radioassay gamma-ray spectrometer for the underground physics community

LDRD

FY15-16: Next-Generation Neutrino and Rare-Event Detection
Gabriel Orebi Gann

Scientific outcomes:

- Construction of apparatus with 338ps timing precision for optical photon detection
- Improvement on separation of Cherenkov and scintillation light in pure LAB
- First successful detection of Cherenkov light component in LAB + 2g/L PPO (high light yield scintillator with fast timing)

Programmatic outcomes:

- Demonstration of new technology
- Enables new generation of large-scale, directional low-threshold detectors
- Application across nuclear, astro, high-energy physics

LDRD

FY16-17: Topmetal Charge Readout Plane for Neutrinoless ββ Decay
Yuan Mei

Scientific outcomes:

- new technology for gaseous TPC readout without avalanche gain
- high spatial and energy resolution
- stable and scalable to large area

Thanks !